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Research article

Diversity and seasonal variation of phytoplankton community in the Santragachi Lake, West Bengal, India

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ABSTRACT
The study of phytoplankton diversity and its seasonal variation was carried out by sampling water taken from the Santragachi Lake, of West Bengal between November 2009 and July 2010. Various physico-chemical variables were recorded and the correlation of this with phytoplankton density was established using Canonical Correspondence Analysis. This showed that the density of phytoplankton was higher when temperature and nutrients were increased. A total of 29 phytoplankton taxa belonging to Chlorophyta (10), Cyanobacteria (8), Charophyta (5), Bacillariophyta (4), and Euglenozoa (2) were recorded from nine samples taken within the study period. Chlorophyta species dominated mostly in variety and percentage composition while Euglenozoa species representatives had the least expression. Bio-indication showed a low diverse community in the monsoon period with better water quality than in pre- and post-monsoon seasons. Various diversity indices (Shannon–Wiener diversity index, Gleason species richness index, Pielou evenness index, and Naughton dominance index) were used to establish the seasonal variation of phytoplankton. The Shannon–Wiener diversity index was most useful in indicating the trophic status of the water as well as the pollution status, which in this case, depicted a moderate level of pollution of this lake.

Keywords: Phytoplankton, Diversity, Seasonal variation, CCA, Santragachi Lake, India

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INTRODUCTION

Phytoplankton constitutes the basic components of the aquatic food chain. They act as primary producers and represent themselves as a direct food source for other aquatic animals. The community composition of phytoplankton is largely influenced by the interaction of a number of physico-chemical factors. Freshwater algal biodiversity and associated physico-chemical factors were studied in India by Veereshakumar and Homani [1]. These types of studies give relevant information about the productive nature of the water bodies under consideration. In India, some lakes and reservoirs have been studied for water quality and fishery purposes [2–6]. Various dynamic features of a lake which depend, to a large extent, on phytoplankton composition, were deciphered by Goldman and Horne [7]. Study of phytoplankton in relation to hydrography has been carried out by several researchers in India [8–10].

Phytoplankton fluctuation and diversity are widely used as biological determinates of water quality in lakes and reservoirs. From phytoplankton density and species composition in tropical lakes, the annual cycle and biological distinctiveness can be established [11,12].

Variation in phytoplankton community composition depends on the availability of nutrients, temperature, light intensity and on other limnological factors. Normally phytoplankton follows a fairly recognizable annual cycle of growth, but sometimes the synchrony in their normal annual cycle is disrupted by explosive growth of some species [13].

Diversity, distribution, and variation in the biotic parameters provide a good indication of energy turnover in aquatic environments [14]. Within these environments phytoplankton are located at the base level and are represented as a major source of organic carbon [15]. Their sensitivity and fluctuation in species composition are usually a suitable explanation to demonstrate the alteration within an ecosystem [16]. Species diversity responds to changes in environmental gradients and may characterize many interactions that can establish the intricate pattern of community structure. Normally, it is found that any slight alteration in environmental status can change diversity until there is no adaptation or gene flow from non-adaptive sources. A high diversity count suggests a healthy ecosystem, the reverse of this indicates a degraded environment. In the latter situation only a few organisms can thrive and flourish, which represents the "paradox of enrichment" effect.

Our present investigation focuses on a comprehensive study of phytoplankton diversity, their species composition, population density, and community characterization. All these factors are important bio-indicators for determining the nutrient content of the lake as a feeding ground for migratory water birds population. The birds use the lake trophic resources during the migration, as well as enriching the water with organic matter. During migration, birds are concentrated, and impact the lake water quality. Establishing how the appearance of avifauna is affected by phytoplankton diversity can also help pinpoint the primary productivity of the lake for zooplankton and other aquatic animals which affect their growth and maturity as well as the nutrition of migratory birds.

STUDY AREA, MORPHOMETRIC CHARACTERISTICS OF THE LAKE

The Santragachi Lake (22°34′60″N, 88°17′60″E) is one of the prominent wetlands of Howrah district, West Bengal, India. It is 8 km away from the central part of Kolkata city. This lake is better known as "Makal Jheel". This particular lake is located on the southern side of Santragachi Railway Station of the South Eastern Railway Government of India (Fig. 1). Santragachi Lake is roughly rectangular in shape and has a total area of 10.87 hectares. The lake has a length of about 914 meters, a width of 305 meters, a perimeter of 2418 meters and the main depth varies from 1.5–2.13 m. This lake has been owned by South-Eastern Railways, but from August 1982 the Forest Department of Government of West Bengal have taken many initiatives to manage and develop this wetland. Every year before the arrival of migratory birds, the Forest Department and local residents take proper steps to maintain a suitable environment for the birds.

MATERIAL AND METHODS

In order to analyze phytoplankton of the Santragachi lake nine phytoplankton samples were collected monthly by scooping water from the lake (in pre-monsoon [March–May], post-monsoon [September–November] and monsoon [June–August]) between 9:30–10:30 am in 400 ml amber color bottles, fixed with Lugol's iodine solution in a 100:1 ratio. The phytoplankton samples collected were left overnight or more to concentrate by the gravimetric method. Sometimes a centrifuge instrument was used for faster sedimentation. After the completion of the sedimentation process, the

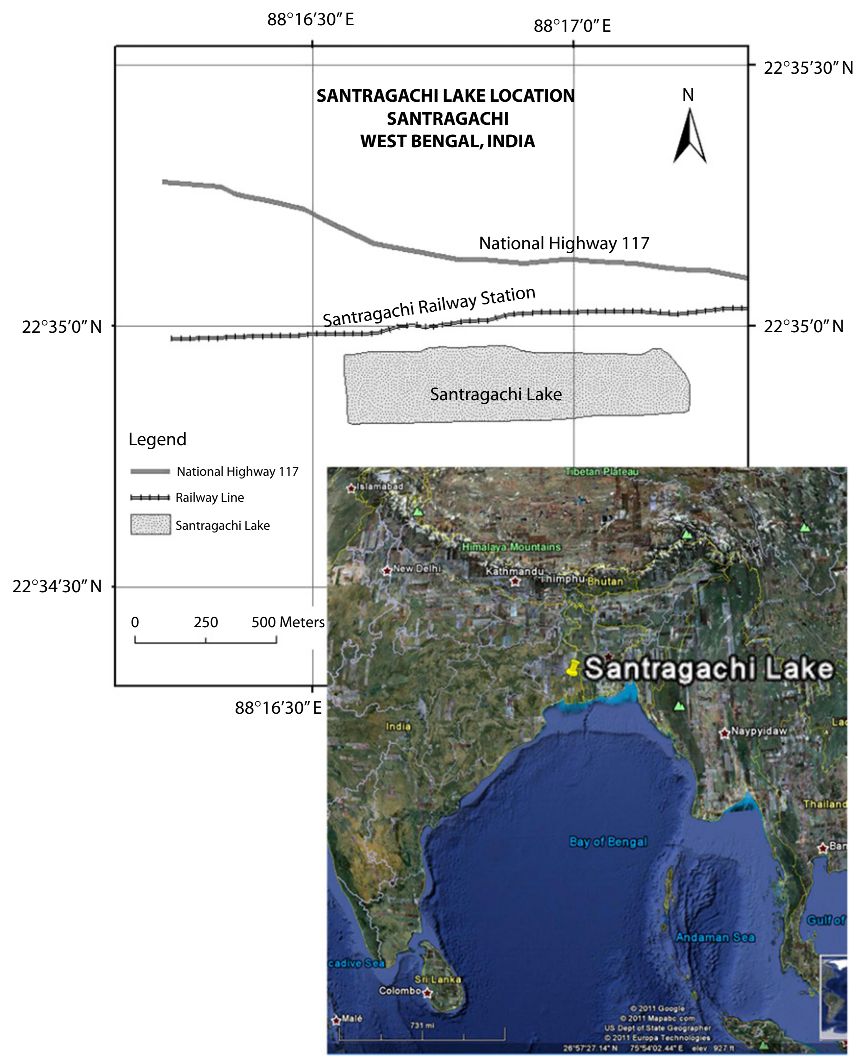

Figure 1. The Santragachi Lake sampling site, West Bengal, India. ARC GIS location map was created by the authors and the large image was taken from Google Earth, 2011

supernatant part was pipetted out and finally the sample was concentrated to 4 ml. The drop count method [17] was followed for quantitative estimation of phytoplankton. Phytoplankton densities were expressed as organisms per liter. The geographic coordinates of the lake under study was determined by the GARMIN GPS 60 device.

Physico-chemical variables such as water temperature, pH, conductivity, dissolved oxygen, nitrate, phosphate, and potassium were analyzed by standard methods [18,19]. Phytoplankton was identified in accordance with standard works [20–25]. Taxonomy was adopted according to the M.D. Guiry and G.M. Guiry's [26] updated system.

The ecological characteristics of algal species were obtained from a previously compiled database [27] for freshwater algae of the world from multiple analyses of algal biodiversity with additions [28,29] for substrate preference, temperature, oxygenation, pH, salinity, organic enrichments, N-uptake metabolism, and trophic states. The ecological groups were separately assessed according to their significance for bio-indications. Species that responded predictably to environmental conditions were used as bio-indicators for particular variables of aquatic ecosystems, the dynamics of which are related to environmental changes.

Phytoplankton density and the percentage composition of each class were calculated.

Species diversity was calculated using Shannon's formula by Odum [30]:

$$H' = \sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N}, \tag{1}$$

where, $N =$ Total number of individuals per liter.

$s =$ is the species number

$n_i =$ is the number of individuals of each species

$H' =$ species diversity in bits of information per individual.

Species richness (SR) was calculated as proposed by [31]:

$$SR = \frac{S-1}{\log_e N} \tag{2}$$

where, $S =$ the number of species representing a particular sample.

$N =$ the natural logarithm of the total number of individuals of all the species within the sample.

Evenness or Equitability (J') index was worked out using the formula of Pielou [32]:

$$J' = \frac{H'}{\log_e S} \tag{3}$$

where, $H' =$ species diversity in bits of information per individual.

$S =$ number of species.

Dominance index (δ) value was determined using the formula of McNaughton [33] as described by Ignatiader and Mimicos [34]:

$$\delta = 100 \frac{(n_1 + n_2)}{N} \tag{4}$$

where $\delta =$ dominance index, which is proportional to the percentage of total standing crop contributed by the two most prominent species n_1 and $n_2 =$ percentage of total population contributed by the two most abundant species in the sample.

$N =$ average value of concentration of total phytoplankton standing crop in the same series of sample.

The Shannon's species diversity index (H′) indicates the diversity (as relative abundance of species dependence function) and the unit is bit i.e., a particular numerical value. The species richness index (SR) is a measure of the richness of phytoplankton genera with a linear correlation between the number of genera and the logarithm of the number of individuals. The evenness index (J′) value depicts the calculation of equality degree in genera abundance. The Naughton's dominance index (δ) measures the percentage of the two or more dominant genera.

The correlation of species composition and environmental variables was established using Canonical Correspondence Analysis (CCA) with CANOCO Program for Windows 4.5 package [35]. Statistical significance of each variable was assessed using the Monte Carlo unrestricted permutation test involving 999 permutations [36]. The abbreviated names of species are given in the taxonomic table (Table 2). CCA plots represent overlap of species in relation to a given combination of environmental variables in a studied month. Arrows represent environmental variables, with the maximal influence value for each variable located at the tip of the arrow [37].

The Pearson correlation coefficient was used to establish the relationship among various environmental variables with phytoplankton density. The linear regression model was performed using SPSS 16.0 for Windows.

RESULTS

The environmental characteristics of the water of Santragachi Lake differed from season to season (Table 1). As the lake was shallow in nature, there was no thermal stratification. The water temperature reached its high (30°C) in March and its lowest value (23.5°C) in November. The moderate value (29°C) was recorded in July i.e., the monsoon season. The findings illustrate that the environmental variables can be divided into two different groups one for water temperature, nitrates

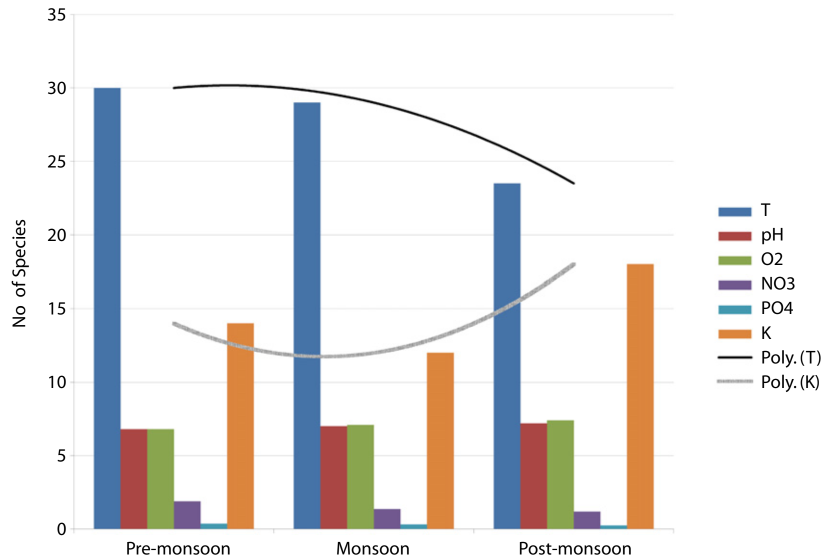

Figure 2. Seasonal variation of environmental variables in the Santragachi Lake during November 2009–July 2010 with polynomial trend lines of the main parameters—temperature (*T*) and potassium (K).

Table 1. Seasonal variation of measured water quality variables and amount of phytoplankton density calculated for a community of the Santragachi Lake during November 2009–July 2010.

Season	Water temperature (°C)	pH	Conductivity (μs/cm)	Dissolved Oxygen (mg/L)	Nitrates (mg/L)	Phosphates (mg/L)	Potassium (mg/L)	Phytoplankton Density (ind./L)
Pre-monsoon	30.0	6.8	244	6.8	1.88	0.367	14	40658
Monsoon	29.0	7.0	262	7.1	1.36	0.312	12	27494
Post-monsoon	23.5	7.2	252	7.4	1.19	0.246	18	34163

and phosphates, which decreased from pre-monsoon to post-monsoon period and the second group with potassium, oxygen and pH, which increased during the study period (Fig. 2). This correlation allowed us to assume that water properties changed under community development.

Phytoplankton communities of the Santragachi Lake from November 2009 to July 2010 consisted of a total of 29 taxa (Table 2) belonging to five taxonomical divisions: Chlorophyta (10), Cyanobacteria (8), Charophyta (5), Bacillariophyta (4), and Euglenozoa (2). The maximum number of phytoplankton taxa was associated with the pre-monsoon season (21), which decreased during the monsoon season to 13 taxa and thereafter increased in the post-monsoon season (17). Among the 29 algal taxa, green algae were present in the highest numbers throughout the three seasons. Their percentage composition for pre-monsoon, monsoon, and post-monsoon communities was 25%, 31% and 32%, respectively (Fig. 3). The Euglenozoa species were very few in number, and their percentage composition value was low: 9.52%, 7.69%, 5.88% for the abovementioned seasonal categories.

Autecological data of the algal species that were identified in the Santragachi Lake indicated that during the monsoon period the community was enriched by species indicators from low salinity and middle pH groups (Table 2). Organic enrichment species-indicators were grouped with respect to the water quality classes from 1–5. The percentage of each class of species indicators showed a lower level of organic pollution in the monsoon period (Fig. 4) as Class 5 indicators of high level organic pollution such as *Euglena viridis* were absent, and Class 3 indicators of low to middle level of organic pollution such as *Dolichospermum affine* were found to be increased.

The total number of algal cells in phytoplankton ranged from a minimal level of 27,494 individuals per liter (June 2010) to a maximal level of 40,658 individuals per liter (March 2010). Phytoplankton

Table 2. Phytoplankton taxa in the Santragachi Lake during the study period November 2009 to July 2010 under pre-monsoon (PR), monsoon (MO), and post-monsoon (PO) time frames with coded names (Code), and autecology of species: Ecological types (Sub): B, benthic; P, planktic; P–B, planktic–benthic; pb, phycobiont; S, soil. Temperature (T): temp, temperate; eterm, eurythermic. Streaming and oxygenation (Oxy): st, standing water; st-str, standing-streaming. Halobity (Sal) [38]: mh, mesohalobe; i, oligohalobious-indifferent; hl, oligohalobious-halophilous; hb, oligohalobious-halophobous. Acidity (pH) [39]: ind, indifferent; alf, alkaliphil. Saprobity [40] (D): es, eurysaprob. Species-specific index of organic pollution [41] (S). Saprobity [41] (Sap): o, oligosaprob; b, beta-mesosaprob; b-o, beta-oligo-mesosaprob; a, alfa-mesosaprob; x, xenosaprob; x-b, xeno-beta-mesosaprob; o-a, oligo-alfa-mesosaprob; b-p, beta-polysaprob; i, eusaprob. Nitrogen uptake metabolism (Aut) [29]: ate, nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen. Trophic state (Tro) [29]: me, meso-eutraphentic; e, eutraphentic.

No	Taxa	Code	PR	MO	PO	Sub	T	Oxy	Sal	pH	D	S	Sap	Aut	Tro
	Cyanobacteria														
1	*Aphanocapsa* sp.	Aphan	1	1	0	-	-	-	-	-	-	-	-	-	-
2	*Coelosphaerium kuetzingianum* Nägeli	CoeKu	1	0	0	P	-	-	i	-	-	1.6	b-o	-	-
3	*Cylindrospermum bengalense* Biswas	CylBe	0	1	0	-	-	-	-	-	-	-	-	-	-
4	*Dolichospermum affine* (Lemmermann) Wacklin, Hoffmann et Komárek	DolAf	1	0	1	P	-	-	i	-	-	2.1	b	-	-
5	*Homoeothrix* sp.	Homoe	0	1	0	-	-	-	-	-	-	-	-	-	-
6	*Microcystis* sp.	Micro	1	0	0	-	-	-	-	-	-	-	-	-	-
7	*Phormidium formosum* (Bory de Saint-Vincent ex Gomont) Anagnostidis et Komárek	PhoFo	1	0	1	P-B, S	-	st	-	-	-	2.8	b-p	-	-
8	*Wollea saccata* (Wolle) Bornet et Flahault	WolSa	0	1	0	-	-	-	-	-	-	-	-	-	-
	Bacillariophyta														
9	*Discostella glomerata* (Bachmann) Houk et Klee	DisGl	1	0	1	-	-	-	-	-	-	-	-	-	-
10	*Navicula trivialis* Lange-Bertalot	NavTr	1	1	1	B	-	st-str	i	alf	es	0.9	x-b	ate	e
11	*Nitzschia linearis* (C. Agardh) W. Smith	NitLi	0	0	1	B	temp	st-str	i	alf	es	0.0	x	ate	me
12	*Pinnularia major* (Kützing) Rabenhorst	PinMa	1	0	1	B	temp	st-str	i	ind	-	0.3	x	ate	me
	Chlorophyta														
13	*Ankistrodesmus falcatus* (Corda) Ralfs	AnkFa	1	1	1	P-B	-	st-str	hb	-	-	2.1	b	-	-
14	*Characium curvatum* G.M. Smith	ChaCu	1	0	1	-	-	-	-	-	-	-	-	-	-
15	*Chlamydomonas globosa* Snow	ChlGl	0	1	0	P, S	-	-	-	-	-	1.9	o-a	-	-
16	*Chlorella vulgaris* Beijerinck	ChlVu	0	1	1	P-B, pb, S	-	-	hl	-	-	3.1	a	-	-
17	*Coelastrum sphaericum* Nägeli	CoeSp	1	0	1	P-B	-	st-str	i	-	-	1.0	o	-	-

(*continued on next page*)

Table 2. (*continued*)

No	Taxa	Code	PR	MO	PO	Sub	T	Oxy	Sal	pH	D	S	Sap	Aut	Tro
18	*Crucigenia tetrapedia* (Kirchner) Kuntze	CruTe	1	0	1	P-B	-	st-str	i	ind	-	1.9	o-a	-	-
19	*Desmodesmus armatus* (Chodat) Hegewald	DesAr	1	1	1	P-B	-	st-str	-	-	-	1.9	o-a	-	-
20	*Pandorina morum* (O.F. Müller) Bory de Saint-Vincent	PanMo	0	1	0	P	-	st	i	-	-	2.1	b	-	-
21	*Pediastrum duplex* Meyen	PedDu	1	1	1	P	-	st-str	i	ind	-	1.8	o-a	-	-
22	*Tetraedron* sp.	Tetra	1	0	1	-	-	-	-	-	-	-	-	-	-
	Charophyta														
23	*Cosmarium quasillus* Lundell	CosQu	1	0	1	-	-	-	-	-	-	-	-	-	-
24	*Mesotaenium* sp.	Mesot	1	0	1	-	-	-	-	-	-	-	-	-	-
25	*Netrium oblongum* (De Bary) Lütkemüller	NetOb	1	0	0	-	-	-	-	-	-	0.8	x-b	-	-
26	*Roya* sp.	Roya	0	1	0	-	-	-	-	-	-	-	-	-	-
27	*Staurastrum cingulum* (W. West et G.S. West) G.M. Smith	StaCi	1	0	0	P	-	st-str	-	-	-	-	-	-	-
	Euglenozoa														
28	*Euglena viridis* (O.F. Müller) Ehrenberg	EugVi	1	0	1	P-B, S	eterm	st-str	mh	ind	-	4.1	i	-	-
29	*Phacus* sp.	Phacu	1	1	0	-	-	-	-	-	-	-	-	-	-

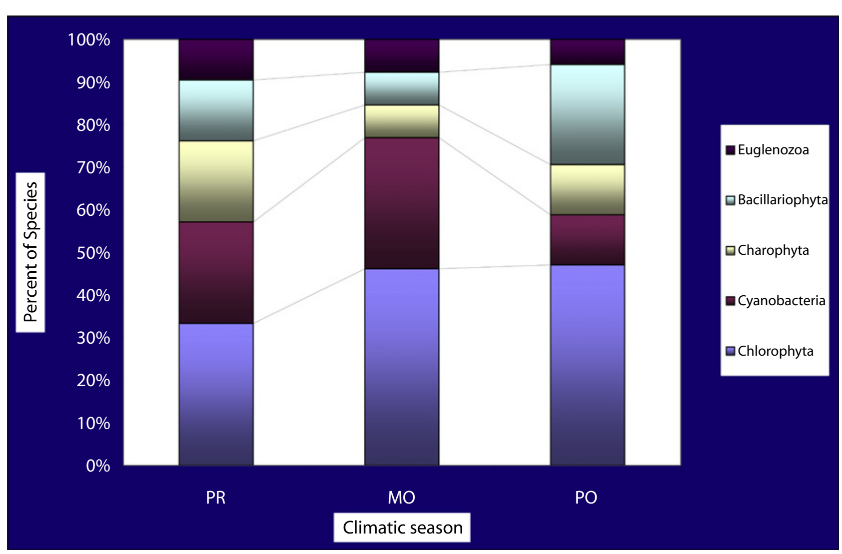

Figure 3. Dynamics of species rate in taxonomic divisions of the Santragachi Lake phytoplankton community over climatic seasons under pre-monsoon (PR), monsoon (MO), and post-monsoon (PO) time frames.

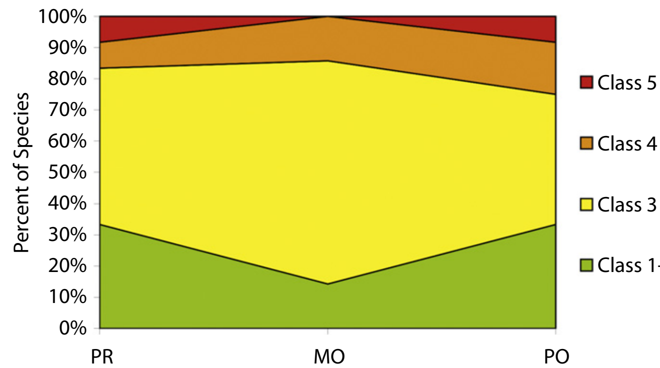

Figure 4. Seasonal percentage dynamic of organic pollution species-indicators in the Santragachi Lake during the study period (November 2009–July 2010). Indicator groups are colored according to the European Framework Directive [42] water quality classes.

density showed a positive correlation with water temperature, nitrates, phosphates, and potassium; and a negative correlation with pH, conductivity, and dissolved oxygen (Table 3). Furthermore, the relation between phytoplankton density and conductivity was of a significant level ($P < 0.05$).

Diversity indices that were calculated by Eqs. (1)–(4) are presented in Fig. 5. The diversity index (H') value varied between 2.344 bit to 2.454 bit. The minimum (2.344 bit) was observed during the monsoon season (July 2010), while the maximum value (highest heterogeneity) detected (2.454 bit) was post-monsoon (November, 2009). The species richness index (SR) varied between 1.786 and 2.814, the minimum value being calculated during the monsoon season and the maximum pre-monsoon (highest number of species). The minimum evenness index (J') value calculated was during pre-monsoon (0.803) and the maximum value (0.914) was documented in the monsoon season. The lowest dominance index (δ) value calculated (0.108) was observed in monsoon season and the highest value (0.140) was pre-monsoon.

DISCUSSION

Temporal changes of the community in the freshwater lake are the most significant driving forces that cause unpredictable variations in phytoplankton composition due to algal species occupying similar ecological niches. Analysis of phytoplankton of this lake showed the presence of 29 representatives, with green algae forming the dominant group. Cyanobacteria, Bacillariophyta, Charophyta, and Euglenozoa species followed in decreasing order of appearance. The planktonic community was not found to be so rich. It could be said that the samples collected from the lake were not of a large enough volume to be representative of the overall species distribution; the findings nevertheless gave a good indication of this.

Table 3. Correlation matrix of physico-chemical variables and phytoplankton density in the Santragachi Lake.

	Phytoplankton Density (ind./L)	Water Temperature (°C)	pH	Conductivity (μs/cm)	Dissolved Oxygen (mg/L)	Nitrates (mg/L)	Phosphates (mg/L)	Potassium (mg/L)
Phytoplankton Density								
Water Temperature	0.124							
pH	−0.493	−0.924						
Conductivity	−0.998[1]	−0.068	0.443					
Dissolved Oxygen	−0.493	−0.924	1[2]	0.443				
Nitrates	0.717	0.780	−0.959	−0.677	−0.959			
Phosphates	0.447	0.943	−0.998[1]	−0.395	−0.998[1]	0.943		
Potassium	0.334	−0.893	0.654	−0.387	0.654	−0.415	−0.693	

[1] Correlation is significant at 0.05 level (2-tailed).
[2] Correlation is significant at 0.01 level (2-tailed).

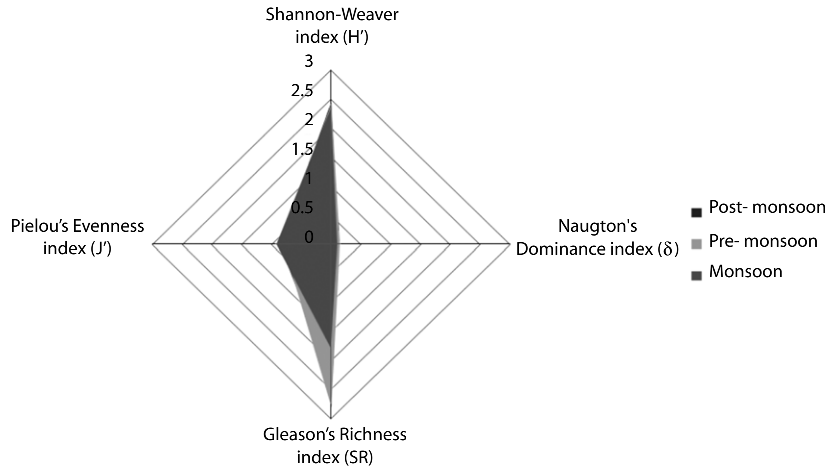

Figure 5. Seasonal variation of diversity indices calculated for the phytoplankton community of the Santragachi Lake during November 2009–July 2010.

The phytoplankton density was found to reach a maximum limit (40,658 ind./L) in the pre-monsoon season, similar to that of other temperate lakes [43]. According to Bailey-Watts [44] and Scheffer [45], surface water phytoplankton of shallow lakes shows less long-term stability than those of stratified lakes. Among the Chlorophyta representatives, *Desmodesmus armatus*, *Pediastrum duplex*, and *Ankistrodesmus falcatus* were the most prevalent throughout the study period. The dominant Cyanobacteria species included *Phormidium formosum, Dolichospermum affine* and *Aphanocapsa*. *Navicula* and *Euglena* were the dominant taxa among Bacillariophyta and Euglenozoa species, respectively. The community was found to change from Chlorophyta-Cyanobacteria-Diatom-Euglenozoa during pre- and post monsoon periods to Chlorophyta-Diatom communities in the monsoon period. *Desmodesmus armatus*, *Pediastrum duplex,* and *Navicula trivialis* were present all year round, whereas the species *Phormidium formosum*, *Dolichospermum affine* from Cyanobacteria and *Euglena* from Euglenozoa were found to be absent, when ordinarily they are abundant in monsoon communities. This finding represents the cyclicity of algal bloom in different seasons [13], and serves as a bio-indicator of the Santragachi Lake pollution as these species prefer organically enriched low disturbed water.

The CCA biplot that was constructed for the Santragachi Lake phytoplankton, (Fig. 6), shows the density, richness and environmental variables for the species analyzed can be divided into two different groups.

Plot 1 shows the species that are impacted by high electrical conductivity, pH and potassium concentration (*Nitzschia linearis*), of which do not survive during the monsoon period. Plot 2 highlights the species that are impacted by increased density under high temperature and nutrient concentration and therefore are sensitive to organic pollution. Remarkably the second group only consisted of four species (from Cyanobacteria and Charophyta) that could flourish in plankton before the monsoon period, which can serve as an organic enrichment indicator.

Appearance and massive growth of phytoplankton in water bodies depend not only on factors such as light and temperature but also on the nutrient load, which affect species composition [46]. In this study, it was found that the availability of nitrates and phosphates in the pre-monsoon and monsoon season were greater in comparison with the post-monsoon season. This availability supports the massive growth of blue green algal members such as *Microcystis* and *Coelosphaerium* species (Table 2, Fig. 6). According to El-Gindy and Dorham [47], the interaction between various physico-chemical and biological factors is the causative regulator for seasonal variation and standing crop of phytoplankton. Statistical analysis of this study's findings revealed a species-environment interaction in the Santragachi Lake plankton. Among the physio-chemical parameters of the Santragachi Lake, water temperature was found to play a pivotal role in regulating various biological activities and growth, showing a positive correlation with phytoplankton density (Figs. 6 and 7). In most cases, an algal community can survive a variation in optimal values up to a certain limit, an increase in temperature can promote greater biological productivity but above or below a specific critical value can create an imbalance.

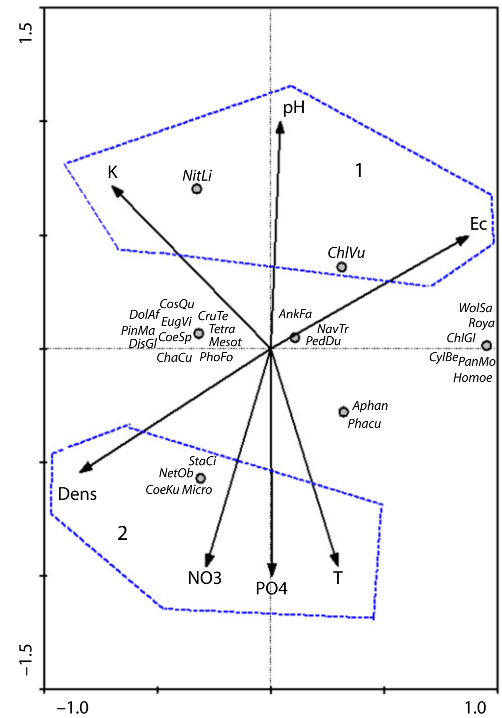

Figure 6. **Canonical Correspondence Analysis (CCA) biplot illustrating the presence of the species (abbreviated names as in Table 2) and environmental variables in the Santragachi Lake during November 2009–July 2010. Species are expressed as circles. Environmental factors are shown as arrows with their origin at average values, extending towards higher values. PH = concentration of proton, K = Potassium concentration, Dens = algal species density, EC = electrical conductivity, T = water temperature, NO3 = Nitrate concentration, PO4 = Phosphate concentration.**

The pH of a water body determines the solubility and biological availability of certain chemical nutrients. Heavy metals are more soluble in lower pH. Here pH established a negative correlation with phytoplankton density. When pH decreases, some algae such as *charophytes* and some greens can withstand the acidic stress and flourish. The low pH tolerant charophytes and green algae depress the overall diversity and build up a new structure of planktonic community in such environments.

Conductivity is the capability of water to conduct an electric current which varies according to the types of ions contained in the solution. A significant negative correlation among phytoplankton density and conductivity was revealed. Usually, it is found that an increase in conductivity increases phytoplankton density. In this study however, an increased conductivity due to toxic heavy metals present in the water from anthropogenic sources and the climatic monsoon effect, resulted in a reduced density and richness of phytoplankton

Dissolved oxygen is a very important factor for the growth and establishment of fish and other aquatic animals. It also indicates the degree of pollution by organic sources. The phytoplankton density of the samples taken represents a negative correlation with dissolved oxygen. Conversely, nitrates, phosphates, and potassium were found to have a positive correlation with phytoplankton density. On comparison of this correlation with the bio-indication of the water quality classes in Fig. 4, a lower level of organic pollution during the monsoon period was seen. This indicated that the Santragachi Lake ecosystem has a very high capacity for self-purification, whereby the nutrients are used for the growth of phytoplankton.

According to Melack [48] the temporal variations of phytoplankton in lakes are related to differences in rainfall. With this in consideration, the Santragachi Lake which receives sufficient monsoon rainfall and associated runoff every June-to- September results in enhanced concentrations of suspended sediment, inorganic substances, and dissolved organic matter, which in turn impacts the volume of species diversity. During the monsoon period the plankton community of the Santragachi Lake is enriched by occasional species, such as *Homoeothrix*, which is developed in various reservoirs of India [49] that come from the periphyton community as a result of disturbance by rainfall.

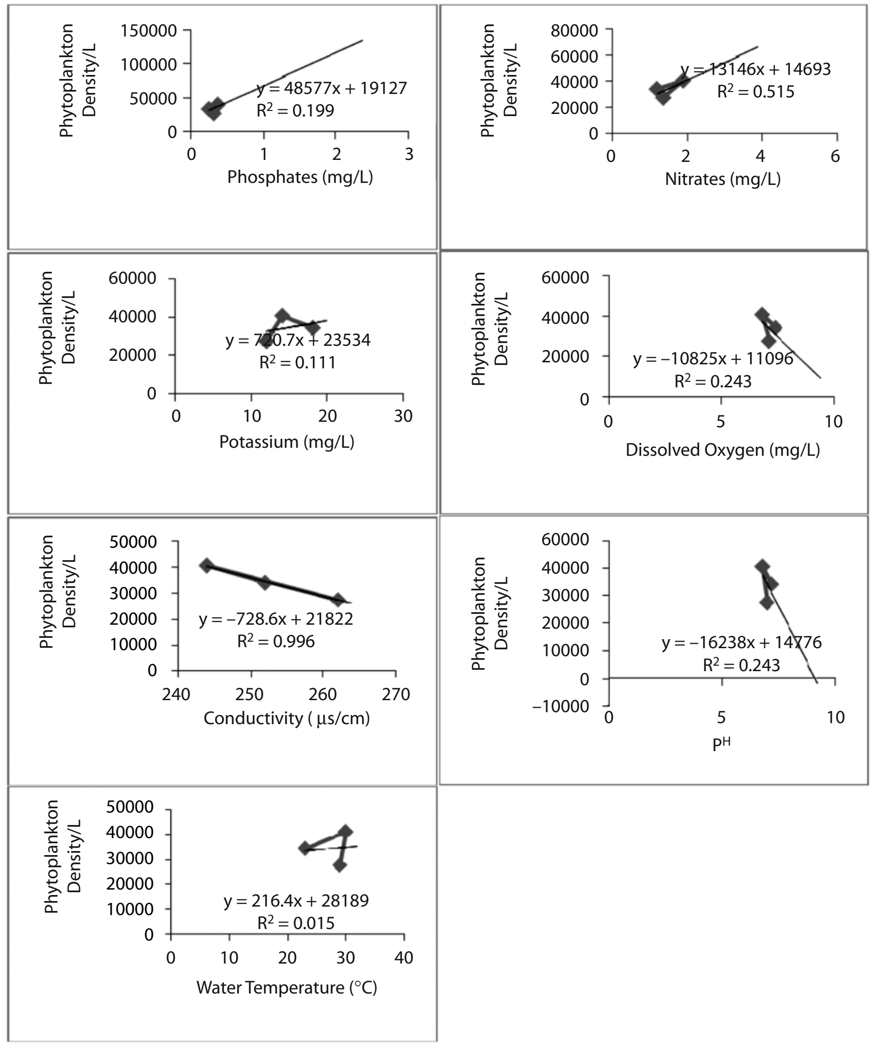

Figure 7. Simple linear regression between phytoplankton densities and phosphates, nitrates, potassium, dissolved oxygen, conductivity, pH and water temperature of the Santragachi Lake.

Nutrient limitation is an important condition for phytoplankton abundance in shallow freshwater lakes [50]. In accordance with the artificial lake fertilization experiment, it was observed that phytoplankton abundance was often controlled by the nitrogen concentration rather than by the concentration of phosphorus [51]. However in the Santragachi Lake, a seasonal increase in the nitrogen-phosphorus ration corresponded with an increase in phytoplankton density.

In this study, the diversity indices popularly used, including species diversity index (H′), species richness index (SR), evenness index (J′), and dominance index (δ) were considered as explanatory variables of eutrophication levels, which to some degree are interrelated. The results of the calculated ecological indexes of the Santragachi Lake (Fig. 5) reflected changes in the phytoplankton community structure as a result of monsoon climate impact. The Shannon diversity index (H′) indicated the lowest phytoplankton structure stability during the monsoon season, whilst the highest heterogeneity and therefore stability of this structure was detected post-monsoon, which corresponded to a less productive trophic status of the lake. The species richness index (SR) was highest during the pre-monsoon period, which correlated with a maximal species richness of the phytoplankton community [32]. The evenness index (J′) revealed a maximum value in the monsoon season. The dominance index (δ) which determines the criteria of species diversity used to identify the main floral and faunal structures of different habitats [52], was of the highest value in the pre-monsoon period and immediately decreased in the monsoon season. When the dominance index was high, the species diversity decreased which resulted in an uneven distribution of other species and vice-versa.

As an example, when the highest evenness index value was 0.914 in the monsoon season, the diversity value was found to be the lowest (2.344). This data supports the theory that the dominance index is opposite to the evenness index [53].

Based on the representations of the organic pollution indicators [54], the lake was considered to have a moderate pollution status. Excessive fishing and washing of cows and buffaloes have been putting constrains on the biodiversity of the lake by excessive nutrient enrichments that have impacted biota in the lake. Along with the addition of pollutants due to the anthropogenic effect, the pollution-load increases day-by-day. Therefore, proper scientific planning is needed to use this lake water effectively.

CONCLUSION

The study findings indicate that climatic variables are expressed in the planktonic algal community fluctuation. Species richness changed with monsoon climatic impact and decreased during the monsoon period. The indices that were calculated for the fluctuations of species densities were helpful in assessing the state of the lake ecosystem. Water pollution was assessed by the methods of bio-indication which was based on predictable responses of each species to environmental changes. It was revealed that organic pollution during the monsoon period decreased in comparison with the pre- and post-monsoon periods. The monsoon rainfall was found to affect the composition of the phytoplankton community and therefore the species dynamic must be carefully monitored.

AUTHORS' CONTRIBUTIONS

Jai Prakash Keshri and Subhabrata Ghosh carried out the sampling and measuring of species density and environmental variables as well as calculated indices. Sophia Barinova taxonomically revised species diversity, ecology and performed statistical analysis of all the presented data. All three authors contributed equally in writing this paper.

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